# THE HALO OCCUPATION NUMBER AND SPATIAL DISTRIBUTION OF 2DF GALAXIES

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**Abstract** We use the clustering results obtained by Madgwick et al. (2003) for a sample of 96,791 2dF galaxies with redshift $0.01 < z < 0.15$ to study the distribution of late-type and early-type galaxies within dark matter haloes of different mass. The adopted method relies on the connection between the distribution of sources within haloes and their clustering properties by focussing on the issue of the halo occupation function i.e. the probability distribution of the number of galaxies brighter than some luminosity threshold hosted by a virialized halo of given mass. Within this framework, the distribution of galaxies within haloes is shown to determine galaxy-galaxy clustering on small scales, being responsible for the observed power-law behaviour at separations $r \lesssim 3$ Mpc. For a more extended analysis, we refer the reader to Magliocchetti & Porciani (2003).

**Keywords:** galaxies: clustering - cosmology: theory - cosmology: observations

## 1. Analysis and Results

Our approach follows the one adopted by Scoccimarro et al. (2001); in this framework, the galaxy-galaxy correlation function can be written as

$$\xi_g(\mathbf{x}-\mathbf{x}') = \xi_g^{1h}(\mathbf{x}-\mathbf{x}') + \xi_g^{2h}(\mathbf{x}-\mathbf{x}'), \tag{1}$$

where the first term $\xi_g^{1h}$ accounts for pairs of galaxies residing within the same halo, while the $\xi_g^{2h}$ represents the contribution coming from galaxies in different haloes. The above quantities can be written as a function of the mean number of galaxies per halo of mass $m$, $\langle N_{\rm gal}(m)\rangle$, of the spread about this mean value (also dependent on the mass of the halo hosting the galaxies), $\langle N^2_{\rm gal}(m)\rangle$, of the mean comoving number density of galaxies, $\bar{n}_g = \int n(m)\langle N_{\rm gal}(m)\rangle dm$ (where $n(m)$ is the halo mass function which gives the number density of dark matter haloes per unit mass and volume), of the two-point cross-correlation function between haloes of mass $m_1$ and $m_2$, $\xi(r, m_1, m_2)$ and finally of the (spatial) density distribution of galaxies within the haloes, $\rho_m(r)$.

$\langle N_{\rm gal}(m)\rangle$ and $\langle N^2_{\rm gal}(m)\rangle$ are the first and second moment of the halo occupation function $p(N_{\rm gal}|m)$ which gives the probability for a halo of specified mass $m$ to contain $N_{\rm gal}$ galaxies. These can be parameterized as $\langle N_{\rm gal}\rangle = 0, (m/m_0)^{\alpha_1}, (m/m_0)^{\alpha_2}$ and $\langle N^2_{\rm gal}\rangle = \alpha(m)^2(\langle N_{\rm gal}\rangle)^2$ with $\alpha(m) = 0$, $\log(m/m_{\rm cut})/\log(m_0/m_{\rm cut}), 1$ in the different mass ranges $m < m_{\rm cut}$, $m_{\rm cut} \leq m < m_0$ and $m \geq m_0$. According to this approach, $m_{\rm cut}$, $m_0$, $\alpha_1$ and $\alpha_2$ are parameters to be determined by comparison with observations.

The last ingredient needed for the description of 2-point galaxy clustering is the spatial distribution of galaxies within their haloes. The first, easiest approach one can take is to assume that galaxies follow the dark matter profile ( Navarro, Frenk & White 1997, hereafter NFW). However, since this assumption is not necessarily true, in the present analysis we also consider spatial distributions of the form $\rho_m(r) \propto (r)^{-\beta}$, with $\beta = 2, 2.5, 3$, where the first value corresponds to the singular isothermal sphere case. All the above profiles have been initially truncated at the virial radius $r_{\rm vir}$, as one expects galaxies to form within virialized regions, where the overdensity is greater than a certain threshold. However, this might not be the only possible choice since for instance – as a consequence of halo-halo merging – galaxies might also be found in the outer regions of the newly-formed halo, at a distance from the center greater than $r_{\rm vir}$.

In order to perform our analysis, we have considered the 4-dimensional grid: $-1 \leq \alpha_1 \leq 2$; $-1 \leq \alpha_2 \leq 2$; $10^9\ m_\odot \leq m_{\rm cut} \leq 10^{13}$; $m_{\rm cut} \leq m_0 \leq m_{\rm cut}\cdot 10^3$. Combinations of these four quantities have then been used to evaluate the mean number density of galaxies $\bar{n}_g$. Only values for $\bar{n}_g$ within $2\sigma$ from the observed ones (derived from the luminosity functions obtained by Madgwick et al. 2002) were accepted and the corresponding values for $\alpha_1$, $\alpha_2$, $m_{\rm cut}$ and $m_0$ have subsequently been plugged into equation (1) to produce – for a specified choice of the distribution profile – the predicted galaxy-galaxy correlation function to be compared with the Madwick et al. (2003) results on late-type and early-type galaxies by means of a least squares ($\chi^2$) fit.

The main conclusions of this work are as follows:

1 Early-type galaxies (see Figure 1) are well described by a halo occupation number of the form broken power-law with $\alpha_1 \simeq -0.2$, $\alpha_2 \simeq 1.1$, $m_{\rm cut} \simeq 10^{12.6} m_\odot$ and $m_0 \simeq 10^{13.5} m_\odot$, where the two quantities which determine the intermediate-to-high mass behaviour of $\langle N_{\rm gal}\rangle$ are measured with a good accuracy.

2 No model can provide a reasonable fit to the correlation function of late-type galaxies since they all show an excess of power with respect to the data on scales $0.5 \lesssim r/[\rm Mpc] \lesssim 2$. In order to obtain an acceptable description of the observations, one has to assume that star-forming galaxies are distributed within haloes of masses comparable to those of

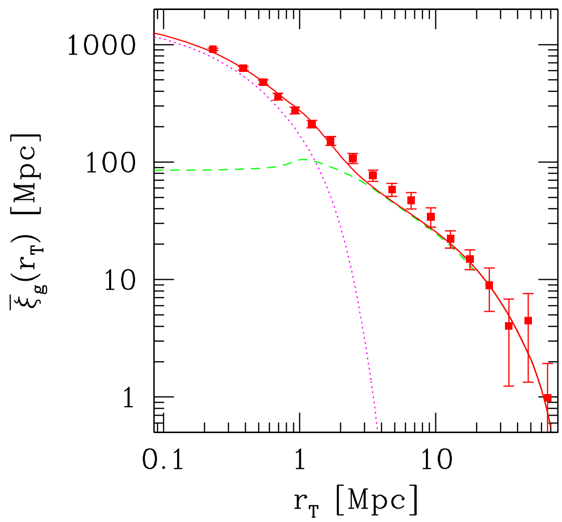


*Figure 1.* Projected correlation function of early-type galaxies. Data-points represent the results from Madgwick et al. (2003), while the solid curve is the best fit to the measurements obtained for a halo number density of the form broken power-law, with $\alpha_1 = -0.2$, $\alpha_2 = 1.1$, $m_{\rm cut} = 10^{12.6} m_\odot$, $m_0 = 10^{13.5} m_\odot$ and for galaxies distributed within their dark matter haloes according to a NFW profile. Dashed and dotted lines respectively indicate the contribution $\xi_g^{2h}$ from galaxies residing in different haloes and the $\xi_g^{1h}$ term originating from galaxies within the same halo.

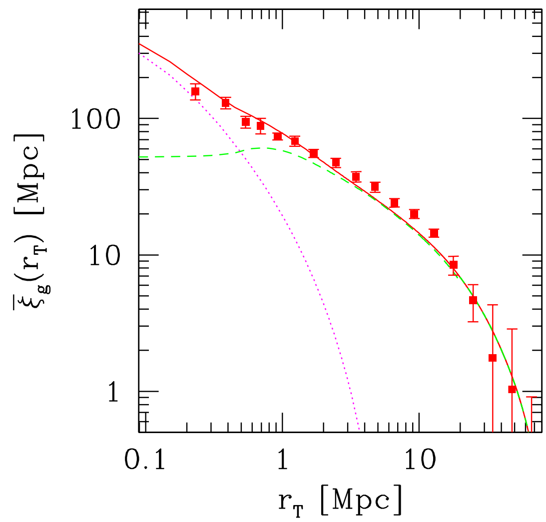


*Figure 2.* Projected correlation function of late-type galaxies. Data-points represent the results from Madgwick et al. (2003), while the solid curve is the best fit to the measurements obtained for a halo number density of the form broken power-law, with $\alpha_1 = -0.4$, $\alpha_2 = 0.7$, $m_{\rm cut} = 10^{11} m_\odot$, $m_0 = 10^{11.4} m_\odot$ and for galaxies distributed within their dark matter haloes according to a NFW profile with $r_{\rm cut} = 2 \cdot r_{\rm vir}$. Dashed and dotted lines respectively indicate the contribution $\xi_g^{2h}$ from galaxies residing in different haloes and the $\xi_g^{1h}$ term originating from galaxies within the same halo.

groups and clusters up to two virial radii. This result is consistent with the phenomenon of morphological segregation whereby late-type galaxies are mostly found in the outer regions of groups or clusters (extending well beyond their virial radii), while passive objects preferentially sink into their centres.

3 With the above result in mind, one finds that late-type galaxies (see Figure 2) can be described by a halo occupation number of the form single power-law with $\alpha_2 \simeq 0.7$, $m_{\rm cut} \simeq 10^{11} m_\odot$ and $m_0 \simeq 10^{11.4} m_\odot$, where the quantities which describe $\langle N_{\rm gal} \rangle$ in the high-mass regime are determined with a high degree of accuracy.

4 Within the framework of our models, galaxies of any kind seem to follow the underlying distribution of dark matter within haloes as they present the same degree of spatial concentration. In fact the data indicates both early-type and late-type galaxies to be distributed within their host haloes according to NFW profiles. We note however that, even though early-type galaxies can also be described by means of a shallower distribution of the form $\rho(r) \propto r^{-\beta}$ with $\beta = 2$, this cannot be accepted as a fair modelling of the data in the case of late-type galaxies which instead allow for somehow steeper $(\beta \simeq 2.5)$ profiles. In no case a $\beta = 3$ density run can provide an acceptable description of the observed correlation function. These conclusions depend somehow on assuming a specific functional form for the second moment of the halo occupation distribution. However, Magliocchetti & Porciani (2003) have shown that there is not much freedom in the choice of this function if one wants to accurately match the observational data.

An interesting point to note is that results on the spatial distribution of galaxies within haloes and on their halo occupation number are independent from each other. There is no degeneracy in the determination of $\langle N_{\rm gal} \rangle$ and $\rho(r)$ as they dominate the behaviour of the two-point correlation function $\xi_g$ at different scales. Different distribution profiles in fact principally determine the slope of $\xi_g$ on small enough ($r \lesssim 1$ Mpc) scales which probe the inner regions of the haloes, while the halo occupation number is mainly responsible for the overall normalization of $\xi_g$ and for its slope on large-to-intermediate scales.

Our analysis shows that late-type galaxies can be hosted in haloes with masses smaller than it is the case for early-type objects. This is probably due to the fact that early-type galaxies are on average more massive (where the term here refers to stellar mass) than star-forming objects, especially if one considers the population of irregulars, and points to a relationship between stellar mass of galaxies and mass of the dark matter haloes which host them.

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